A problem analysis and program for

Watershed-Management Research

in the White Mountains of New Hampshire

by George R. Trimble, Jr.

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About the Author ...

GEORGE R. TRIMBLE, JR., has devoted much of his forestry career to studies of forest watershed problems. A graduate of the University of Maine Forestry School, he joined the U. S. Forest Service in 1937, and came to the Northeastern Forest Experiment Station in 1939. After wartime service with other agencies, he returned to the Experiment Station in 1946. He served for a time on the staff of the Flood Control Survey, and later conducted watershed management research both in West Virginia and New Hampshire. At present he is leader of the Experiment Station's research center at Elkins, West Virginia.

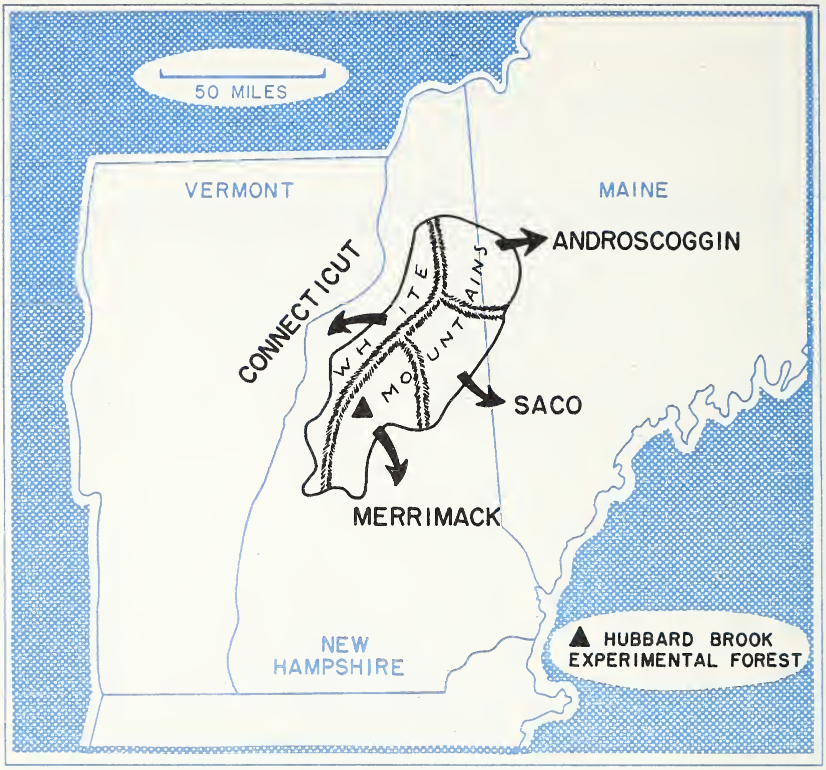

Figure 1.--*The area being used for watershed management research in New England. Many of the studies are being made on the Hubbard Brook Experimental Forest.*

Introduction

THE U. S. Forest Service was authorized by Congress in the late summer of 1954 to conduct watershed management research in New Hampshire. The purpose of this work is to determine the effect of forest cover on streamflow: the influence of forest cover type, forest condition, and forest treatment practices on water yield, rate of delivery, and on water quality. This is the first program of its kind in New England.

This problem analysis is intended to serve as a basis for that program. It is designed specifically for the White Mountain area of northern New England, which lies mostly in New Hampshire. However, research results should apply to other areas in the Northeast that have similar climate, topography, geology, soils, and cover.

This analysis, the foundation for a long-range program of research, is prepared primarily for the research man on the ground. Though the analysis, in many cases, leads up to the working plan, its intent is not to define a rigid program of research, but rather to serve as a guide. The field of watershed management is developing rapidly: better instrumentation, improved techniques, and better understanding of natural relationships are adding to our knowledge; they are also constantly widening the scope of watershed research. Consistent with these changes, the analysis will periodically be reviewed, modified, and enlarged to keep the research program realistic and vital.

It should be recognized also that problems change; time may prove that the proportional emphasis given problems described in this analysis was faulty. However, the research program, designed to solve practical problems whose pertinence is obvious, also employs studies that will yield basic as well as empirical answers. With the passing of time and the increasing importance of water, the basic data we obtain will very likely have multiple uses in helping to solve new and complex problems.

Justification for this research program stems from the following interlocking concepts:

- Water is a natural resource that may be limited in quantity and quality of supply; at times of flood flows, it can be highly destructive.

- Forested headwater areas are the most important sources of high-quality water: carefully managed, they provide natural protection against damaging floods.

- Four of the six major river drainages in New England have as their source the forested watersheds of the White Mountains.

- Treatment of forest watersheds affects the quantity, distribution, and quality of streamflow.
- There is little or no quantitative information for this region on the influences of forest treatment on streamflow.

THE GENERAL SITUATION

The White Mountains do not cover a large area. In aggregate they measure about 2,000 square miles in a block roughly 75 miles long and 30 miles wide. However, streamflow from this region form the headwaters of rivers whose basins cover two-thirds of New England; these rivers are the Connecticut, Merrimac, Saco, and Androscoggin (fig. 1).

Streams arising in these heavily-forested mountains are both an attraction and a threat. At once they are appealing and memorable features of a landscape that attracts well over a million vacationists a year--again, they are carriers of high water that floods and devastates downstream communities. At times streams run sparkling clear; occasionally, they are heavy with bedload and suspended sediment. When water demands are lowest, streams are often full: but during the summer, when demands are high, streams are at their lowest.

Water problems, then, in this forested mountain area are those of quantity and quality. What is the influence of present-day forest cover on characteristics of streamflow? What is the influence of current forest management practices? And what practices can be developed to lessen these problems? To answer these questions is the objective of the research program to be described.

The problem of quantity concerns both floods and water-use. Each is becoming more serious. With rapid development of river valleys, floods, once considered minor, now inflict heavy damage. Ever-increasing demands for water stem from several factors: population growth, greater per capita use of water, increased need for industrial water supplies, and the as yet hardly felt demand for irrigation water.

The problem of water quality, in connection with this research program, concerns erosion-caused sedimentation from forest lands. This is separate from the problem of water pollution from industrial waste and sewage.

Water quantity and quality problems are related. During times of excess water, erosion, landsliding, and streambank-cutting greatly increase bedload and sedimentation. When streamflow is low, pollution is accentuated because there is less water to dilute existing pollutants. A stream that rates as clean at normal levels may become unfit for many uses at low flows when it still carries the same volume of polluting material.

Much of the watershed management research in the White Mountains will apply to other areas in the Northeast,

particularly the Berkshires of western Massachusetts, the Green Mountains in Vermont, and the Adirondacks of New York. Forest cover types and climate in those regions are similar to those in the White Mountains. However, there are soil, topographic, and geologic differences in some areas that will require careful consideration before applying White Mountain results.

THE RESEARCH AREA

The watershed research program will be concentrated in the Hubbard Brook Experimental Forest (fig. 1), a 7,500-acre tract set aside from the White Mountain National Forest. The Hubbard Brook region lies near the village of West Thornton, New Hampshire, 13 miles north of Plymouth on U. S. Route 3. It is a tree-covered area situated on rugged terrain, with timber types, soil, and geology representative of the White Mountains.

Hubbard Brook, which drains from west to east, enters the Pemigewasset River south of West Thornton. Within this watershed are several small (35- to 200-acre) subwatersheds, all draining north or south into Hubbard Brook, and all suitable for gaging. Elevations in the area range from approximately 700 feet to a little over 3,300 feet.

Cover types.--The watershed is completely forested. Major types include northern hardwoods, mixed hardwood-softwood, spruce-fir, and paper birch. The area was logged over 40 to 50 years ago and all merchantable softwoods and the more accessible merchantable hardwoods were removed. Approximately half of the area would classify as merchantable sawtimber today.

Geology.--All of the watershed was glaciated. Both bedrock and rock material deposited by the glacier are granitic and schistose in nature. Two geologic formations underlie the area: Kinsman (granite) and Littleton (schist).

Soils.--Most of the soil types are podzolic, a few are brown podzolic. Sandy loams and fine sandy loams predominate, and mor humus types are more prevalent than mull. Average pH of the soil is about 5.0.

Climate.--The climate is a modified continental type with long, cold winters, accompanied by heavy snowfall, and comparatively short, cool summers. Precipitation of 40 to 50 inches--of which one-fourth to one-third is snow--is well distributed throughout the year. Average annual temperature is around 40°F. with an average January temperature of 16° and an average July temperature of 68°.

Problems of Water Quality

IT is important that streamflow in the White Mountains be of high quality: most public water supplies come from surface water; there are few wells in the region. In the northern half of New Hampshire, for instance, of 32 sources of public water supply, 5 are subsurface, 25 are surface, and 2 are a combination. Also, the cleaner the streamflow that leaves the White Mountains, the more valuable it is to downstream municipal and industrial users.

For the most part, natural surface waters of this region are soft and low in suspended sediment; pH is usually between 6.0 and 6.5. The water is clean. Even after heavy rains, streams generally clear so quickly that most people believe water quality no problem. There has been little erosion from undisturbed wooded areas. However, on bare steep roads and banks, rill and gully erosion are prevalent. Once the protective covering of organic matter is removed, running water cuts quickly into mineral soil, washing sediment into streams to cause such problems as the following:

> The small town of Lancaster, N.H., (population 2,300) gets its water supply from Garland Brook, which rises in an area of rugged forest land. Water for the town is obtained by diverting part of the stream into water mains. There is no settling basin or reservoir; just a dam and a small settling area in front of a screen house. From 1953 to 1955 the town had considerable trouble from silt in the water system. The silt came from stream channels plugged by hurricane storms, and from surface runoff from poorly located logging roads. Silting control cost over $5,000 of which over $2,500 was spent on measures to reduce washing on logging roads. Since then, on the portion of the watershed lying on the White Mountain National Forest, logging has been restricted to snow and ice roads to minimize erosion.

Sources of sediment are geologic (normal) and man-caused (accelerated) erosion. The first type results from stream-cutting, slides on precipitous slopes, and flooding and washing during unusually heavy runoff. Man at times also causes these kinds of erosion, so it is impossible to separate the two types quantitatively. In places geologic erosion is obvious--slides and stream-cutting on steep slopes undisturbed by man. On the other hand, in many areas of slides and active stream-cutting, man has disturbed the original environment through fire, timber cutting, log driving, and road building. These activities have modified plant cover, altered the condition of humus, and encroached upon stream courses.

The type of sediment produced depends largely on soil types. The soils of the White Mountains are derived mostly from granite and schist glacial till; they are light-textured, mostly sandy and fine sandy loams. Surface soils

have little binding material (clay) and are weakly aggregated and erosive. In places the deeper till contains much silt and clay. Beds of heavier material normally lie several feet below the surface.

Water containing over a certain amount of suspended sediment requires treatment before use. The limiting point of usefulness varies: for domestic water supplies, it is 10 parts per million (standard of the U.S. Public Health Service); for making paper, cleanliness depends on the quality of paper to be made (high quality paper demands very clean water, coarser paper less clean); soft drink bottling and dyeing processes demand very clean water; the manufacture of steel is less exacting. Yet, few industries can use dirty water; they must go to the expense of cleaning it first.

In New Hampshire, water pollution problems have had legal status since passage of a water pollution law in 1947 that provides for the classification of all surface waters into five groups:

A. Acceptable for public water supply after disinfection. Quality uniformly excellent.

B-1. Acceptable for bathing and recreation, fish habitat, and public water supply after treatment. High esthetic value.

B-2. Acceptable for recreational boating, fish habitat, industrial and public water supplies only after adequate treatment.

C. Acceptable for recreational boating, fish habitat, and industrial water supply.

D. Acceptable for transportation of sewage and industrial waste without nuisance.

Enforcement of this law has been based on the principle of preventing any degrading of water once it has been classified. Emphasis has been on organic pollution; at present, the State makes no measurement of suspended sediment in its stream-classification program. However, as the law refers to degrading of water quality without reference to the material responsible, a logging operator who fills a stream with sediment and degrades a municipal water supply is legally in defiance of the law and could be subject to prosecution. This poses a challenging question to research: Can timber be harvested in a watershed drained by a Class "A" brook without degrading the water?

Sedimentation damage is no less objectionable because it is geologic than if it were man-caused: unstable streambeds and landslides are undesirable in a water-supply area no matter what their cause. Once begun, how can geologic erosion be controlled? Can areas of geologic erosion be recognized and eliminated from consideration as prospective municipal watersheds? Can man minimize or prevent such damage?

Studies involving the effect of land-use practices on the quality of water depend not only on measurements of erosion from the land but also on measurements of water quality. This involves measurement of suspended sediment and bedload.

Suspended sediment, the fine material easily borne and suspended in water, is less prevalent than in many areas of the United States. This is due to the relative coarseness of soils in this region. At times and in places, however, it presents difficulties. Landslides, road cuts, and flowing streams frequently expose underlying beds of silt and clay that become sources of suspended sediment. In some municipal watersheds enough fine material has been exposed and entered water mains to make the water unpotable.

Suspended sediment is measured on a weight basis directly from water samples. Turbidity measurements involve an ocular estimate of the departure of the appearance of water from clear. Easier to make, they have often been substituted for measurements of suspended sediment in gross approximation work.

Bedload, another type of sediment, consists mostly of heavier particles of soil, gravel, and rocks which, being too heavy to float, are rolled along the bottom of streams. There is no sharp line between bedload and suspended sediment; in flood time, some sand may be carried in suspension which in quieter water would be bedload. Though bedload does not reduce water quality in the same way that suspended sediment does, it is highly damaging. It fills reservoirs; it clogs intake pipes; it plugs stream channels, adding to flood damages; and it damages fish habitat.

Measurement of bedload is probably the most important measurement in water-quality studies in this area. At present the only known method of measuring bedload is to trap it in a basin of some sort. Hydraulic research may produce simpler and more efficient ways to measure bedload.

THE ROAD PROBLEM

Roads are the greatest single cause of accelerated erosion, the major source of man-caused sediment in forested areas. A survey of logging road conditions in New England following the floods that accompanied the 1954 and 1955 hurricanes supports this statement: Sedimentation and flood damages from streams flowing from wooded areas were obviously related to the type and condition of the roads.[1]

For purposes of discussion, roads are divided into three categories: public roads, logging truck roads, and skid trails.

[1]Unpublished report, Northeastern Forest Experiment Station. 1955.

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Public Roads

Roads of all types, from multi-lane concrete speedways to dirt truck trails, traverse the White Mountains. Where not well located, well constructed, and well maintained, these roadways serve as concentration areas for flashy runoff. They are heavy contributors of sediment that may come from unpaved road surface, from cut and fill banks, or, if roads concentrate enough runoff to cut gullies, from the nearby forest floor.

The State Highway Department, the towns, the Bureau of Public Roads, and the U. S. Forest Service may be either solely responsible or share jointly in the control of a road. In respect to watershed management, many of these roads are poorly located and constructed, and they offer much the same watershed problems as do logging roads, the specific concern of this research program.

Logging Truck Roads

Any dirt road through a forest creates an unprotected, erosive, and largely impervious surface. It presents the problems of how to keep the road in place and how to keep surface runoff and sediment out of the water course.

Generally logging truch roads are of a much lower standard than public roads. Less carefully laid out, they are usually located on steeper grades. And a problem peculiar to them, as contrasted to public roads, is that after an area is logged, these roads are often abandoned until time to log again. This practice poses the question of post-logging care: How to stabilize logging roads so that they will be usable for the next operation?

Logging truck roads are a serious problem in White Mountain watershed management. Careless location and poor construction and maintenance of these roads has lowered water quality in a number of watersheds, in several cases it has even caused public agitation against logging in municipal watersheds. The White Mountain National Forest has about 100,000 acres under special-use permits as municipal water supply areas. These areas are open for other uses such as lumbering and hunting. Continued multiple-use management of these areas, and of others to be so designated in the future, may depend on whether logging roads can be built and maintained without unduly reducing water quality.

Skid Trails

If logging truck roads are a somewhat transitory and crude extension of public roads, then skid trails are as a still more temporary and primitive extension of logging truck roads. Skid trails, varying even more than logging

roads, range from single-log horse trails to well-graded carry-cart roads that approach truck roads in appearance.

The opportunity for surface washing on skid trails varies widely, affected mostly by season of skidding. Skidding on snow and ice results in little damage, while ground-skidding on steep slopes in the summer may cause deep gullying. In making skid trails, desirable objectives include correct location as regards slope and stream courses, and successful post-logging stabilization. Measures to meet these objectives differ with each type of skidding. Since it is difficult to drain skid trails while they are being used, logging should be organized so a minimum of time is spent on any one area. Skid trails, being temporary, can usually be revegetated. This is not true of logging truck roads designed for future use.

Studies Needed

Principles of logging road location, construction, and maintenance in accordance with good watershed management have been established. However, these principles are not well-known, nor have they been tested or demonstrated in the White Mountains. Specific information based on studies in this region is needed to permit location, construction, and maintenance of logging roads that will not impair water quality.

Logging-road research involves a multitude of factors. For example, runoff and erosion are effected by soil erodibility, soil compaction, and intensity of use. Then too, study is required of the watershed aspects of summer versus winter logging; i. e., logging over dirt roads compared to logging over snow and ice. Logging equipment constitutes still another field of research, particularly its effect on degree and area of soil disturbance. Also, revegetation methods for disturbed areas needs review. With these many factors to consider, development of a research program requires first a survey of logging problems. Then, studies of road hydrology and methods of logging could be designed, keeping in mind their demonstration possibilities. The over-all program may include the following:

- Survey to define the logging road and skid trail problem. This will entail inspections of logged areas, taking into account type of equipment and season of logging, percent of the area occupied by roads and skid trails, and approximations of type and amount of erosion.

- Road hydrology studies to define road practices compatible with good watershed management. Location, grade, and drainage will be analyzed in relation to their effect on erosion and water quality. Post-logging treatment with vegetation, debris, and other methods of soil stabilization will also be studied.

- Methods of logging, especially the effects of different types of logging equipment on soil disturbance and water quality, should be determined. Also the effects of logging in different seasons should be ascertained, particularly a comparison of the effects of logging on bare ground to logging on snow roads.

- Demonstrations of road research should be planned to illustrate good watershed road and skid trail practices as well as serve research functions.

LANDSLIDES

Landslides produce considerable water-borne material in the White Mountains. Much of this is coarse and is carried as bedload. To a great extent landslides are geologic phenomena--part of the normal process of land levelling. However, they can be aggravated by man through disturbance of protective vegetation and by cutting roads across steep, unstable slopes. This may be the case in the White Mountains; certainly the potential for man-caused landslides is ever present.

On a clear day, from the higher peaks, slides can be seen in great number. They stand out prominently as long, ugly scars, often stretching from ridgetop or base of cliff into the valley below. They show up clearly on aerial photographs. Though no figures are available on the number of slides in this area, an estimate might place them in the hundreds.

Slides result when the forces holding a soil on a slope are overcome by unusually heavy rains or snow melt, by a very heavy snow pack, by freezing and thawing, or by a combination of these. Sharpe, in a thorough treatise of the subject, stresses the part played by frost action (15). At least a partial cause may be timber growth: theoretically, on slopes in delicate balance, increasing weight as timber stands grow may start slides. Thus, some slopes may be stable when covered by young growth, but become unstable with increasing stand age.

Ranger Carl Burgtorf, formerly of the Littleton District of the White Mountain National Forest, considers landslides a primary source of water pollution in that district. For example:

> The town of Littleton, N.H., has a water-supply reservoir on the north branch of Gale River. Because of slides, the river is unstable, and frequent bulldozing is needed to clear the reservoir of deposits. In fall 1954, during hurricane Carol, a tremendous slide blocked the river several miles above the reservoir, and a 45-foot-high head of water built up before the stream broke through the slide. This wall of water carried trees, humus, boulders, gravel, and sand; it cut banks as it went, adding to its load of debris; it uncovered beds of "blue clay", which further lowered quality of the water. A year later, during low flows, the stream was discolored and gave off a bad odor like swamp water.

Careful examination revealed that this slide is about 1/3 mile long with an average grade of about 60 percent. In places, the trench cut by sliding material is 25 feet below the normal soil surface and up to 150 feet wide. In only a few stretches did the material move over bedrock; in most places the bottom is soil. The slide, still raw in 1956, showed no indication of healing--a source of quick runoff and sediment. Several old, partially healed slides of various ages are found in the same vicinity. Aerial photos taken previous to 1954 indicated that the big slide started at the location of an older one. The previous slide, however, extended from the stream only about one-third of the length of the new slide. It occurred in an area that had been cut over 40 to 50 years ago. There is no way of knowing if the cutting in any way triggered the older slide.

Another type of slide damage is the filling up of recreational bodies of water. To illustrate:

> The hurricanes of 1954 brought landslides that dammed the upper reaches of Mad River in Campton, N. H. When the dams broke, the high water carried enormous loads of debris downstream. Much of it piled into Campton Pond, a favorite body of water for thousands of summer visitors to the White Mountains. The fishing and swimming facilities, particularly the latter, were greatly impaired and will remain so until an extensive and expensive clean-up job can be done.

Since man's activities in these mountains will undoubtedly multiply, and since the use of these mountain watersheds as sources of domestic water supplies is increasing, information on the White Mountain landslides and their causes should be obtained.

Studies Needed

A reconnaissance survey should be made of White Mountain slides to determine:

- The magnitude and nature of the problem involved as it concerns water supplies--both actual and potential.
- The causes of these slides--if possible.
- Identifiable conditions where slides occur so that municipal watersheds will not be located in such areas.
- The pattern of slide revegetation.

This project is quite suitable for a cooperative study between watershed research technicians and a graduate student majoring in geomorphology. From this survey, studies may be designed to obtain detailed information on various phases of the slide problem.

OTHER PROBLEMS

Many streams in the White Mountain area are unstable. They cut their banks; they change channels; they carry tre-

mendous amounts of coarse material as bedload. Much of this may be because they have not yet returned to--or eroded out --their pre-glacier streambeds on solid rock. They are flowing through unstable glacial till and rock debris. Under these conditions, stream cutting is a geologic process unrelated to man's activities.

The amount of geologic erosion in undisturbed watersheds should be determined to serve as a basis of comparison to water-quality measurements in logged watersheds. Remedial measures for down-stream stabilication have been developed, but there has been little work in this country on stabilizing mountain streams; water quality and bedload measurements may suggest the need for this research. The effect of bedload on fish habitat also deserves study.

A minor problem affecting water quality may develop from the numerous foot and ski trails in the White Mountain area. When foot trails are carefully located in respect to grade and stream courses, and where they are drained in appropriate places they present no problem. But because of poor location in the past, some foot trails have become intermittent stream channels and have eroded badly.

Ski trails are deliberately located on steep slopes and may be 50 feet wide in places with no forest or brush cover to protect them from pounding rain. Ski slopes are even more unprotected since they are more open. Accordingly, both types of ski runs are naturally subject to erosion. Revegetation to grasses and grains has been the principal means of erosion prevention. The Soil Conservation Service in this area has done considerable work in developing seed mixtures and treatments for this purpose.

No specific research is recommended at present for foot and ski trails. However, the results of some road-erosion studies, especially revegetation experiments, may apply to these uses. Also, studies of the effect of forest cover removal on snow accumulation and melt and soil freezing will be applicable to ski areas. As more recreational areas develop, their impact on water quality and quantity may require more detailed study.

Problems of Water Quantity

PRECIPITATION in the White Mountains ranges from 40 to 70 inches per year. Runoff ranges from 20 to 50 inches so that from 50 to 70 percent of the rainfall and snow gets into streamflow. One-fourth to one-third of White Mountain precipitation falls as snow, the dominant form of precipitation from December to April. Considerable rain also falls in this period.

It is pertinent to compare the percentage of yearly precipitation that runs off as streamflow in this area with the runoff percentage for some other regions in the United States: White Mountains, 50-70 percent; West Virginia, 40-50 percent; Southern Wyoming, 3-5 percent; Delaware, 35-45 percent; the United States as a whole, 29 percent.[2] Compared to most parts of the United States, annual recovery of precipitation as runoff in the White Mountains is high. Thus, there is not as much to gain percentage-wise by developing methods of increasing water yield.

Precipitation and streamflow are sufficient for present needs and probably for forseeable future needs. Nevertheless, while precipitation throughout the year is fairly well distributed, streamflow is not uniform. At times the region suffers from an excess of water with resulting flood damage, while at other periods water is deficient in terms of demand. For instance, streamflow records at Woodstock, N. H., from 1940 to 1950 show that only 3.6 percent of the yearly flow of the Pemigewasset River occurred in the month of August. For the same period, 24.6 percent of the yearly flow ran off in May.[3] Yet average precipitation in that region is slightly greater in August than in May: the greater runoff in May, of course, comes from the spring melting of snowpack.

The water quantity problems are, then, high flows and low flows--too much water and not enough. The problem for research is to determine if and how these conditions can be improved.

FLOODS

Floods rank foremost in the problem of water quantity. The roster of damaging floods in the past 30 years begins in the fall of 1927 when excessive rains on saturated soil resulted in damaging flooding in New England. The March flood of 1936 from rainfall and melting snow set new peaks. The September 1938 flood was one of the first of recent hurricane-accompanied floods. Excessive rainfall with little snow-melt contribution marked the flood of late December, 1948. Most recent hurricane-floods occurred in 1954 and 1955.

Damage has been enormous (13). Take for example damages reported from one of the rivers rising in the White Mountains, the Merrimac: Flood damages for the total reach of the river in 1936 were estimated at $35,000,000, with 60

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[2]Based on runoff and precipitation figures taken from several sources, including: Langbein, W. B., et al., "Annual runoff in the United States," U. S. Geol. Survey Circ. 52, 14 pp., 1949; and Kittredge, Joseph Jr., "The magnitude and regional distribution of water losses influenced by vegetation," Jour. Forestry 36: 775-778, 1938.

[3]Calculated from records published in U. S. Geol. Survey Water-Supply Paper 1301, "Compilation of records of surface waters of the United States through September 1950. Part 1-A, North Atlantic slope basins, Maine to Connecticut." 380 pp.

percent in Massachusetts and 40 percent in New Hampshire. Agricultural losses were estimated at $800,000 and would have been more if the flood had occurred during the growing season. Highway and railroad damages were set at $7,400,000. The remainder of the destruction was largely in urban and industrial areas.

In the 1927 flood, total damage on the Merrimac was relatively lower than on some other rivers; it totaled only $2,365,000. Most of this damage occurred in the headwater reaches in New Hampshire. Average annual flood and erosion damages in the Merrimac basin are estimated as follows, based on 1949 price levels:

Flood-water damages:	
Headwater areas	$ 264,000
Main stem and tributaries	3,101,400
	3,365,400
Loss of income from yield:	
Decline due to erosion of cropland	20,000
Total	$ 3,386,300

Before considering the relationship of forests to floods, it may be enlightening to consider the reduction of flood damages that can be achieved through construction of flood-control dams:[4]

> Flood-control projects are expensive in this region as compared with other parts of the country. Good reservoir sites in the critical areas are scarce; large ones are seldom available except at prohibitive cost. As a result, the economies involved in constructing very large storage dams or multiple-purpose power and flood-control dams usually cannot be realized. Moreover, most river valleys in New England are short and narrow and the cost of each flood-control project must be charged off against a smaller valley area than is the usual case in other regions.
>
> On the other hand, flood-control benefits are large in some parts of New England where much valuable property is concentrated on the flood plain. Thus the Corps of Engineers has submitted economic justifications for numerous projects in the Connecticut River Basin, but no projects have been recommended in the State of Maine.
>
> The Corps claims that its construction program in New England, when completed, will prevent about 60 percent of the estimated 32 million dollars of average annual flood damage which would occur if there were no flood-control projects. The Corps also states that about ten million dollars of this damage is being prevented by flood-control structures it has already completed.
>
> The Corps' completed projects are now preventing much flood damage. Proposed projects would almost double the effectiveness of the Federal flood-control program. It should be

[4]From New England Business Review, March 1956.

> pointed out, however, that about 55 percent of the average annual flood damage which now occurs in New England cannot be economically prevented by the construction of additional storage reservoirs, dikes, and channel improvements.
>
> The Corps of Engineers cannot justify projects on many small streams. Also, much property is located outside of local protection works and near waterways where flooding will occur occasionally after all the Federal structures are completed. In addition, local protection works do not guarantee one hundred percent protection. The Corps usually designs its structures to contain a flood somewhat larger than the maximum flood of record, but it cannot justify building so much protection that any city or town can never be inundated.
>
> Thus, living near any waterway, even when it is protected by Federal flood-control works, involves a calculated risk.

It is obvious from this statement that big structures will not completely solve the flood problem in New England. It remains an important watershed problem for investigation.

Studies Needed

Research in forest-flood relationships can be divided into three lines of endeavor: (1) determining the effect of present forest cover on floods, (2) determining the effect of commonly used management practices on floods, and (3) developing means of reducing floods through forest management practices.

Determining the effect of present forest cover.--The forest-flood relationship for the White Mountains badly needs clarification. Creation of the White Mountain National Forest was justified largely from the standpoint of flood control. Yet, there is practically no information as to the contribution forested watersheds make to flood runoff. Per unit area, what peak flows can be expected from small forested watersheds? How do these compare with downstream unit yields from multi-use watersheds? How do they compare with peaks from clear-cut watersheds? In short, what are the flood-control functions of forested watersheds and how are they exerted?

Determining the effect of commonly-used management practices.--The next series of questions proceed logically: What are the effects of current timber-harvesting practices? Given several small watersheds that support commercial stands, what is the effect on peak flows of cutting by accepted procedures? Moreover, how are these effects brought about in relation to fundamental changes in the hydrology of these watersheds?

Developing means of reducing floods.--Studies employed in the first two endeavors will undoubtedly lead to detection of those forest factors that have the greatest influence on reducing peak flows. The question then is how to

maintain or even improve these conditions.

The above three approaches will require intensive study of all factors known to be associated with floods: vegetational, climatic, and soil. They will require research on both watershed and plot bases. They will require a study of flood-producing conditions by seasons; and this will require an analysis of surface, subsurface, and base flows in relation to their sources. The needs for research are great; an early task is to select the projects that will yield the most information.

LOW FLOWS

From low flows stem two types of problems: water quality and water shortage. The problem of water quality or pollution is the more general: sharp reduction in summer flow reduces the carrying capacity for pollutants and thereby lowers water quality. The water-shortage problem applies particularly to municipal watersheds as they experience inadequate summer flows.

Solution of the water-quality problem as related to low flows revolves around whether summer water yields can be increased by forest cutting practices. E. A. Colman (1) summarizes possibilities of water yield control in New England as follows:

> The combination of short growing season and relatively low year-round temperatures sets the spruce-fir region apart as having a growth rate slower than that of any vegetative region which receives an adequate moisture supply...slow growth is an especially important consideration in relation to vegetative management for water-yield control. Any openings made in the forest cover will persist with little change for a long time. Therefore, any water-yield benefits must be clearly established before widespread watershed treatments of this kind are undertaken...because the growing season is longer and warmer in the northern hardwood region the opportunities for altering vegetation are greater... changes, once made, are more difficult to maintain.

The problem of low flows is greatly affected by the underground storage available to feed summer streamflow. This depends upon the occurrence of thick layers of porous materials or large crevices in bed rock. According to Richard P. Goldthwait (2), ground-water in this area is found chiefly in open cracks in bedrock. Informed geologists believe these are neither frequent, deep, nor wide. Aquifers underlying the White Mountains generally yield less than 50 gallons per minute to wells (16).

If the groundwater storage reservoir is of such limited capacity that it is filled every year regardless of variations in snow conditions, then measures to reduce snow interception and increase snow catch can add little to ground storage for later use unless the snow melt period is prolonged.

It is not known whether groundwater storage in the White Mountains is ever completely filled during the summer. Well records from other sections of New England indicate that groundwater is rarely recharged to the maximum during this period.

A distinction should be made between uplands and river valleys. Wells located in the latter often produce heavy flows of water. The towns of Conway, North Conway, and Berlin get their domestic water supplies from wells on river bottoms.

Studies Needed

The influence of forest cover on water yield can be studied using the three approaches outlined for forest-flood studies; namely, the influence of present cover, the effect of management practices, and the development of practices aimed specifically at increasing summer yields. Again, these could be studied both on watershed and plot basis.

By analyzing streamflow hydrographs, the relation of winter and spring precipitation and snow melt to summer base flow can be established. The proportion of base flow to total flow both annually and seasonally should be determined during periods of watershed calibration and re-determined for periods of treatment.

Hydrologic Processes

THE influence of forest cover on flood flows and low flows could be deduced solely from watershed studies--by calibrating a series of small forested watersheds, subjecting them to different treatments; and from streamflow records, calculating the effects of the treatments on peak and low flows. These procedures have two major limitations: first, there are not enough experimental watersheds to test all the treatments necessary in different soils and forest types; second, this type of study does not provide reasons for streamflow changes so results cannot be applied to other areas with any degree of confidence.

To circumvent these shortcomings, the effects of treatment on hydrologic processes are studied. These are the processes that influence the amount of precipitation that becomes streamflow and its rate of delivery to the stream channel: interception of rainfall, snow accumulation and melt, infiltration and surface runoff, percolation, soil moisture storage, evapo-transpiration, and streamflow (as affected by physical features).

To understand the influence of these processes and to utilize this knowledge requires:

- Determining through fundamental studies how each process influences the disposition of precipitation, and how this can be predicted in quantitative terms.

- Determining for experimental watersheds the influence of each process on the disposition of precipitation under pre-treatment and treated conditions, perhaps from or in connection with fundamental studies.

- Utilizing knowledge of fundamental relationships and results from watershed studies, to develop means of integrating the effects of these processes into a prediction system by which the results of different watershed treatments can be estimated.

For example, in the light of the above three requirements the snow accumulation and melt processes can be considered as follows:

- Determine how the forest stand condition influences accumulation of snow and rate of snow melt, and then determine how this can be predicted from a parameter that describes this forest stand influence.

- For the experimental watershed, determine snow conditions under both pre-treatment and post-treatment conditions.

- Integrate the effects of the stand on snow accumulation and melt with the effects of the other processes. This should indicate the net effect of the snow condition on the quantity of streamflow, peak flows, and low flows on the experimental watershed. From all of these data develop a method of predicting the effect of snow conditions (under given stand conditions) on streamflow. Test and refine the prediction method against results from other experimental watersheds.

These three steps, applied to each process, cover a large part of the research program. The threefold objectives of determining how each process works, the degree of its effectiveness on experimental watersheds, and the development and testing of prediction methods, cannot be reached by any simple, clear-cut procedures. Attainment of these objectives will entail considerable exploratory work in methodology.

Each of the seven processes listed will be discussed in reference to: research field, importance of subject, status of present knowledge, deficiencies in knowledge, and type of studies needed.

INTERCEPTION OF RAINFALL

Research field.--The effect of forest canopy on the interception of rainfall.

Importance of subject.--Rainfall intercepted by and evaporated from vegetation never reaches the ground. Thus it does not become a part of surface runoff, soil moisture, or ground water. If this loss is appreciable and is affected by forest treatment, then it must be considered in watershed management research.

Status of present knowledge.--Considerable work has been done to determine the effect of forest canopy on the amount of rainfall that reaches the ground. Results show that interception is influenced by stand stocking, structure, age, species, composition, ground cover, and condition of foliage; that is, whether the crown is bare or in leaf. It also varies with amount and intensity of precipitation.

In most of the 6 to 8 studies conducted in the East, stemflow was not measured, so these give only estimates of gross interception. Net interception (stemflow measured and deducted) was determined in two studies. One, in the southern Appalachians, showed that old-growth hardwoods intercepted 14 percent of rainfall in summer and 5 percent in winter; young shortleaf pine intercepted 14 percent of rainfall in summer and 10 percent in winter. These data were collected by the Southeastern Experiment Station.

Data collected by the Northeastern Forest Experiment Station in Pennsylvania show that net interception in scrub oak was 6 to 7 percent of annual rainfall, and 16 percent in tall hardwoods. This included some snow.

Table 1.--Average annual rainfall interception, by forest types

(dense stands at age of greatest interception)

Forest type	Gross interception		Stemflow		Net interception	
	With leaves	Without leaves	With leave.	Without leaves	With leaves	Without leaves
	Percent	Percent	Percent	Percent	Percent	Percent
Northern hardwoods	20	17	5	10	15	7
Aspen-birch	15	12	5	8	10	4
Spruce-spruce fir	35	--	3	--	32	--
White pine	30	--	4	--	26	--
Hemlock	30	--	2	--	28	--
Red pine	32	--	3	--	29	--

Standards of interception research vary from mere observations to carefully designed and controlled experiments. Thus a review of past work is handicapped not only by the lack of information on all the many variables of cover and storm condition, but also by the lack of standardization in research techniques. For purposes of the problem analysis, available data have been adjusted in table 1 for application to this region. These figures are merely approximations to indicate the nature and importance of interception.

Usually, a dense even-aged softwood stand will intercept about one-fourth to more than one-third of the precipitation that falls, the more tolerant (thicker crowns) and stiffer needled conifers intercepting the larger amounts. In softwoods stemflow is generally insignificant, but still it varies with branching habit and bark roughness, as well as with storm characteristics.

Hardwoods intercept less precipitation than softwoods, and they intercept more in full leaf than when bare. Stemflow on hardwoods varies greatly depending on position of the tree in the canopy, smoothness of bark, branching habit, and season of the year. On some smooth-bark trees such as beech, stemflow may amount to 15 percent of storm precipitation when the trees are not in leaf. Rough-bark species such as hickory or maple (after they get old) have low stemflows--often less than 5 percent. Stemflow is less for summer rains than for winter rains. It also varies with the storm pattern, tending to be less in storms with a low amount and low intensity of rainfall.

From table 1 it is apparent that conifers can markedly reduce the amount of precipitation reaching the ground. Where water is vital for man's use, it may be profitable to reduce conifer cover to the minimum consistent with soil protection.

On the other hand, where floods are a major threat, any increase in interception may be an advantage. Not only may interception during a flood-producing storm be of consequence, but also previous interception will have tended to reduce the amount of water stored in the ground. This means that more storage space will be available for precipitation of flood-producing magnitude.

This discussion of possible interception effects ignores the influence of intercepted rainfall in reducing evapo-transpiration. If, as seems quite probable, there is a partial balancing of interception effects by a reduction of evapo-transpiration, then interception during the growing season may have much less effect on soil moisture and streamflow than has been supposed. Net effects of interception on streamflow must be determined from its effect on the evapo-transpiration process.

Deficiencies in knowledge.--(1) Little is known about the possible dampening effect on evapo-transpiration by interception. (2) A simple measurement of canopy density that would correlate well with interception would be useful. (3) Date on interception is needed to help determine the water balance on experimental watersheds.

Type of studies needed.--Studies are needed to determine how much the rainfall interception during the growing season reduces evapo-transpiration from the soil. The dampening effect of interception can be studied in conjunction with soil moisture measurements, comparing for instance, rates of soil moisture depletion immediately after rainfall with those after the foliage has dried. Considerable ex-

ploratory work will be necessary before designing such a study.

Instrumental measurements of canopy density should be made and correlated with interception effect. Canopy density thus measured should also be tested as a function of forest type, basal area, and stand age.

SNOW ACCUMULATION AND MELT

Research field.--The influence of environmental conditions, particularly forest cover, on the accumulation of snow and the pattern of snow melt. As the term is used here, snow melt refers to reduction of the water equivalent of the snow pack; that is, actual loss of water from the pack.

Importance of the subject.--In the White Mountains, winter precipitation is largely snow. It builds up a blanket of many inches of snow water--a reservoir or a flood threat. Snow interception is thus accumulative and at the time of snow-pack melt may account for several inches of water.

The rate of snow melt has considerable bearing on flood flows and on amounts of groundwater or reservoir storage. Generally, the faster snow melts, the greater the danger of floods and the less opportunity to store water for later use.

Where snow water is an important part of streamflow--as it is in the White Mountains--the possibility of affecting its accumulation and melt by cover manipulation deserves study.

Status of present knowledge.--Snow has been studied in this country and in Europe by agencies and individuals too numerous to list. Winter sports groups, power companies, government conservation and agricultural agencies, universities, and the armed services have contributed to our knowledge. At present, the Snow, Ice, and Permafrost Research Establishment of the Corps of U.S. Army Engineers publishes voluminous reports of snow work done throughout the world.

In the United States, most studies have been conducted in the high country of the West where snow water forms most of the available water supplies. But because of differences in climate and cover, much of this research is not applicable to Northeastern conditions. A good example of a climatic difference is the common occurrence of midwinter thaws in the Northeast, which does not occur in Western mountains.

Snow Accumulation Or Interception

Interception of snow is related to the type, distribution, and density of crown cover. For instance, softwoods

intercept more than hardwoods. Among conifers those with heavier and stiffer foliage intercept the most snow; interception is greatest at the bole and decreases toward the edge of the crown; fully-stocked stands intercept more than understocked stands; stands at time of maximum growth rate intercept more than younger or older stands.

Interception by reproduction and lesser vegetation is of little importance where these plants are covered by the snow pack. This differs from rainfall interception, in which evan a brush and grass cover may intercept measurable precipitation.

The interception of snow is also related to climatic conditions or storm variables: interception is greater with a wet snow that clings to the vegetation; it is greater in calm weather than in windy weather; and interception is greater when the snow pack accumulates from a series of small storms than when it builds up from a few large storms.

At the edge of a forest opening, the interception effect diminishes rapidly. In a study made in a northern hardwood pole stand in the White Mountains, there was no discernible interception 10 feet past the canopy edge (14).

Three studies show actual or relative snow interception for different conditions in the Northeast:

- Morey found that a 60-year-old northern hardwood forest in Vermont intercepted 9 percent of the snow water in one snowstorm, while a thick spruce stand intercepted 44 percent. Average snowfall in the open for this storm was 0.82 inch of snow water.[5]

- During the winter of 1954-55, a study made at Bartlett, N. H., showed that pole-sized hardwood stands intercepted more snow than sawtimber stands. Average accumulated snow water (at time of maximum snowpack) in pole stands was 7 to 10 percent less than in 1/3- to 1-acre openings in the stand. Sawtimber stands contained 3 to 5 percent less snow water than similar small openings (14).

- From measurements for a number of storms, W. L. Maule (11) in Connecticut found the following relationships between cover types and snow depth:

Type	Order of snow accumulation	Order of snow retention
Open fields	1	5
Hardwoods	2	4
Red pine	5	2
Norway spruce	6	
White pine	3	1
Hemlock	4	3

[5]Morey, H.F. Report of hydrologic observations made on the Ottauquechee River watershed, spring of 1942. Unpublished report, Northeastern Forest Experiment Station.

According to Maule:

> The lowest depth of snow...for Norway spruce...was due to the denseness of the crown and the stiffness and great number of needles in the spruce branches. While the snowfall in the spruce cover type was about half the depth of that in the red and white pine stands, it was retained for as long a period as in the red pine stand. Low wind velocity, plus reduction of direct insolation upon the snow in the thick spruce and pine stands probably explains how they are able to retain the light snowfall for such periods.
>
> The white pine, having longer and softer needles and more flexible branches, allows a greater quantity of snow to reach the ground and offers better protection against direct insolation.
>
> In rating the different cover types on their ability, based on time, to retain snow the following would be the most logical arrangement, the type holding the snow the longest being placed first: white pine, red pine, Norway spruce, hemlock, hardwood, and the open fields. The white pine ranks first, in the case of the conifers, because of two abilities; it holds the snow the longest, and it permits the greatest depth of snow on the ground. It is suggested that these are the ideal factors when considering the kind of trees to plant on the catchment areas of reservoirs used for power or water supply.

Based on references quoted, plus data from other references, table 2 was prepared as an approximation for snow-interception conditions in the White Mountain area.

Table 2.--Average annual snow interception by forest types (dense stands at age of greatest interception)

Types	Net interception*
	Percent
Northern hardwoods	10
Aspen-birch	7
Spruce or spruce-fir	35
White pine	25
Hemlock	25
Red pine	30

*Note that these values are within 1 to 5 percent of interception values estimated for rainfall.

Snow Melt

Before snow melts, it must reach a certain density; this is called ripening. In the East, a ripe snow pack may have a profile density of no more than 30 percent. Western observers generally use the range of 40 to 50 percent density for ripe snow. Their observations are made on deep snow packs that presumably have uniformly dense profiles. No doubt these snow packs are well compacted (due to depth and

thus weight), and this alone increases density. In the western mountains, below-freezing weather is usually continuous during the period of snow pack accumulation.

Eastern snow packs are generally much shallower; thus weight is less a factor in increasing density. In addition, most snow packs in the East are subjected to periods of melt during accumulation, warm spells in winter often accompanied by rain. Accordingly, the density of the snow pack varies with depth so that melting in a snow pack of an average 30 percent density may well be occurring largely from denser lower layers.

Rates of snow melt are affected by a number of factors. Morey lists the following: air temperature, wind, solar radiation, aspect, elevation, degree of slope, width of valley, cover type, density of cover. The three climatic factors can be considered basic; the others, as modifying variables.

Kittredge (5) states in regard to snow melt: "Obviously, melting is a resultant of the balance between gains and losses of heat. The gains are derived from turbulent air exchange, condensation, incoming radiation, warm rain, and the soil." (Incidentally, snow reflects about 75 percent of the radiation. The losses of heat result chiefly from outgoing radiation and evaporation.) Means of evaluating each heat source, including allowances for cloudiness and the albedo of the snow, have been suggested by W. T. Wilson (18). His figures for extreme conditions give a total of 3.8 inches water equivalent melted in half a day. R. E. Horton (3) reports 0.05 inch water equivalent for the rate of melting in the sun (per day-degree F above freezing) in New York State. Heavy rains, ordinarily associated with temperatures above freezing, may accelerate the rate of melting.

Colman (1) makes this interesting observation on the effect of vegetation on snow melt:

> The heat-insulating effect of vegetation operates both in the crown canopy above the snow and in the litter accumulation beneath it. Above, the canopy shields snow on the ground from the radiant energy of the sun, and hence decreases its melting rate. Below, the litter shields it from heat radiated by the soil, with the same effect. Insulation in the crown canopy is achieved not so much by reflection of radiant energy as by absorption. It is probable that part of this re-radiated heat reaches the snow.

The question of how much and how long snow water can be retained remains to be answered for the White Mountain area--particularly in relation to any changes man can affect by manipulation of cover. To catch as much snow as possible and prolong the melt period as long as possible, Maule (11) recommends plantations of mixed hardwoods and softwoods. He feels that mixed stands catch more snow than softwood stands and have a lower melting rate than hardwoods. Morey corroborates this: He found that mixed hardwood-conifer stands in

Vermont had snow on the ground longer than either nearby pure softwood or pure hardwood stands.

Sartz and Trimble (14) conclude from preliminary investigations in northern hardwoods that on north-facing slopes narrow plots cut in an east-west direction retain snow longer than larger openings or under the hardwood canopy. The width of the plots best suited to do this would depend on tree height and the steepness of the slope. Taller trees and steeper slopes would permit wider plots since increasing tree height and increasing slope-percent would throw longer shadows.

Deficiencies in knowledge.--(1) The effect of forest type and condition on snow accumulation and melt should be determined. (2) The effect of forest cutting practices on accumulation and melt should be determined. (3) A measure of canopy density is needed to correlate with snow interception and rate of melt. (4) The effect of humus in retarding snow melt should be investigated. (5) The contribution of snow melt to streamflow should be analyzed. (6) Prediction methods for estimating melt from climatic data should be developed for flood-warning purposes.

Type of studies needed.--In conducting snow studies, the magnitude of maximum cover effects should be established in terms of accumulated snow water and in days of prolongation of melting. Next some intermediate points within the ranges to facilitate satisfactory interpolation should be determined. Modifying influences of climatic and topographic variables on cover effects should also be studied.

The major cover variables whose influence requires study are species or type of forest cover, density, age, structure (even versus uneven-aged), and shape and size of openings or cuttings. Influence of the major climatic variables--solar radiation, wind, rain, fog--will differ from year to year so that interception and snow melt studies should be repeated several seasons. The major soil and topographic variables are elevation, aspect, steepness of slope, humus type and depth.

Integration of the many influential factors to predict snow behavior will probably require a multiple-regression approach. A single canopy measurement, expressing effects of several stand factors on snow interception and melt, would facilitate predictions.

Another possible procedure would be to construct slopes--perhaps of wood and soil--of various aspects and degrees of steepness to determine the effects of slope and aspect differences on snow melt.

INFILTRATION AND SURFACE RUNOFF

Research field.--Infiltration is the entrance of water into the soil surface. The infiltration rate is the rate of water entrance into the surface soil, expressed in inches per hour. Water running over the ground surface out-

side of stream channels is surface runoff. The two phenomena--infiltration and surface runoff--are obviously related: when the infiltration rate exceeds the rate at which water is applied to the soil surface (either by precipitation or snow melt), there is no surface runoff.

It is important to emphasize that the term "stream" includes not only the larger permanent streams but also the tiny rills and rivulets that carry water only during and immediately after rains or periods of snow melt. Surface runoff involves, therefore, not long distances of overland flow, but only the relatively short distances to the nearest minor channels.

Importance of subject.--Surface runoff reaches streams quickly; it usually forms the bulk of flood flows, especially from non-forest land. Surface runoff is water lost to the area on which the precipitation falls; it serves neither as groundwater for later streamflow or wells, nor as moisture for plant growth. In addition, it erodes soil and carries sediment to streams.

From observation, surface runoff rarely occurs in White Mountain forests; infiltration rates may be considered high, except on road surfaces or other areas of drastic disturbance such as landslides and log skidways, or in areas where concrete frost has formed. Subsurface flow is probably the most important component of storm runoff from forests in this area.

Status of present knowledge.--Numerous studies have given us a good understanding, on a qualitative basis, of factors affecting infiltration and surface runoff. Cover and soil conditions that tend to make for higher infiltration and thus lower surface runoff include: a dense vegetative cover, organic matter on and mixed in the upper soil, coarse-textured and dry soil, numerous root holes, active soil life, irregular and uncompacted soil surface, ahd high permeability throughout the profile.

In relation to land-use, the floor of undisturbed old-growth forests has the highest infiltration rates of any type cover. Infiltration rates are generally reduced by burning, grazing, and repeated heavy cuttings. Agricultural land, hayland, and pasture usually have higher infiltration rates than bare land or row crops. Moreover, the evolution of vegetative cover on well-drained soil from bare land to the climax association is accompanied by an increase in infiltration rates.

Two methods are used to measure infiltration. The first utilizes artificial application of water to the top of natural soil surfaces of limited area. Numerous techniques and types of equipment such as soil cores, ring infiltrometers, and "rain makers" are used. All are subject to various errors; several are too expensive for wide use. The "rain makers" or infiltrometers using simulated rainfall technique have been most successful. Colman (1) says of them:

They have been used with considerable success to predict the quantity and rate of surface runoff on hillside plots as large as 1/40 acre and the stormflow of a few acres. But so far they have not provided a very useful means for predicting the stormflow of large streams. In view of the limitations of these instruments it seems likely that their greatest usefulness will continue to be in indicating the rate of rainfall that is likely to cause surface runoff, and not in predicting quantitatively the distribution of surface runoff to the stormflow of a stream.

The second method derives infiltration rates on a watershed basis from runoff and rainfall data. This is a gross method that averages and approximates values since any watershed large enough to produce runoff has considerable variation in infiltration conditions. Its use is justified for flood routing purposes, but it has little place in research. Some investigators have used percolation and soil moisture storage parameters in conjunction with rainfall and runoff data to estimate infiltration rates for different soil-cover conditions within the same watershed. Though this should improve infiltration estimates, the improvement cannot be verified; consequently, the method does not provide a useful tool for research.

Infiltration studies have been very useful in a qualitative way to show which land-use practices increase and which decrease infiltration rates and thus surface runoff. Perhaps more than any other single parameter, infiltration rates have been used to distinguish "good" from "poor" land-use practices.

Deficiencies in knowledge:--There are no infiltration data for the various forest conditions and soil types of the White Mountains. As long as surface runoff is not evident in these areas, no data are needed. But information is needed for those localized conditions where surface runoff occurs: forest roads, land-slides, foot-trails, and other areas of disturbance. Also lacking is knowledge of the effect of frost on infiltration. This suggests that infiltration measurements be included in any study of frost and forest conditions.

Type of studies needed.--Infiltration tests of one kind or another will be made in conjunction with several types of investigations. For example, ring infiltration tests will be made to show the effects of various kinds of soil freezing in producing surface runoff, to show compaction effects and revegetation effects on logging roads, and to determine differences in infiltration among humus types and depths.

In general, studies will be limited to conditions where infiltration strongly influences surface runoff and water quality. No attempt will be made to develop infiltration rates or indexes for various soil cover-topographic complexes.

PERCOLATION

Research field.--Percolation is the movement of water through the soil profile. This movement takes place in the macropore space or the region of detention storage. While infiltration concerns the entrance of water into the soil surface, percolation is the downward movement of water within the soil body. Percolation, like infiltration, is generally spoken of as a rate. It is measured as the depth of water in inches that passes a given point in the soil in an hour. For example, the percolation rate in a given soil is 1.5 inches per hour at a point 6 inches from the soil surface. Often, however, representative percolation rates are determined for soil horizons and are assumed to be nearly uniform for each horizon.

Importance of the subject.--The percolation rate helps set the infiltration rate. If the percolation rate is high throughout a soil profile, infiltration is high unless the soil surface is sealed. At any point in the soil profile where the percolation rate is lower than the rate at which water reaches it, water will back up and produce surface runoff or subsurface flow. Thus percolation rates are influential in determining whether the rain water or snow melt goes to surface runoff, subsurface flow, or ground water. As surface runoff appears negligible in this area, its main effect will be on subsurface runoff.

Status of present knowledge.--Since percolating water moves in macropore space, its rate of movement is increased by the factors that tend to produce a loose soil: large amounts of organic matter, coarse-textured soil, uncompacted soil, root activity, activity of soil flora and fauna, absence of concrete freezing, and any other physical or chemical conditions favoring soil aggregation. Percolation rates also vary with some of the more intrinsic soil characteristics. For example, percolation rates are greater in kaolinite clay than in montmorilinite clay because the latter swells when wet. Man's influence in modifying percolation rates is greatest on the upper soil horizons, which mark the potential root zone.

The standard method used in determining percolation rates is to take undisturbed soil cores in the field and, in a laboratory, measure the rate at which water passes through them. There are numerous variations in equipment and procedures. Results are relative and do not simulate actual field rates. Lysimeters have also been used to measure percolation, but they are too expensive for wide application. In spite of weakness, these methods have helped to show the effect of forest practices.

As with infiltration rates, adjustments of relative percolation rates to rainfall and runoff data have been worked out to obtain estimated rates. While such methods have justified use for flood-control surveys and other extensive work they are not considered research procedures.

Deficiencies in knowledge.--There are no data on percolation rates for soil profiles in this area. Some relative percolation rates for humus layers, determined for conditions in northwest Pennsylvania, may have some applicability. Core percolation rates should be determined for different soil conditions in the Hubbard Brook Forest area, measurements should be made to determine how these are affected by various forest practices.

Studies needed.--Two types of studies are needed: (1) a survey to determine percolation rates for major existing soil conditions on the watersheds, and (2) a study to determine the direction, magnitude, and depth of changes in percolation rates within the soil profile with changes in cover and use.

The methods used should be carefully chosen; to facilitate comparisons as far as possible, all studies should be made with the same equipment and techniques. Soil analyses should be made of factors known to influence percolation rates and storage capacities such as aggregation, organic-matter content, volume weight, and texture.

SOIL MOISTURE STORAGE

Research field.--Soil moisture storage is divided into two main phases: detention storage and retention storage.

Detention storage: The water held temporarily in storage in the macropores above the point of field capacity but below the point of saturation capacity; it is subject to loss through gravity. Because of entrapped air, the volume of water in detention storage after thorough wetting is always somewhat less than macropore space.

Retention storage: The amount of water held in the soil after the excess of gravitational water has drained away and percolation has virtually ceased. This is water below the point of field capacity.

Retention storage is generally subdivided into water available to plants--capillary water held between field capacity and permanent wilting percentage; and water unavailable to plants--water held below the permanent wilting percentage.

These parameters may be expressed as a percentage of soil weight or volume, but expression on a volume basis is more meaningful in watershed research work. Distribution of water, solids, and space by volume in a saturated soil of fine or medium texture is about as follows (5):

	Percent
Pore space resistance wetting (entrapped air)	10
Detention storage	18

Retention storage	29
Capillary moisture	20
Wilting percentage	9
Solid particles	43

Importance of subject.--The nature and amount of soil moisture storage have far-reaching effects on watershed relationships. Most soil water movement takes place in the macropores. With an adequate volume of these pores throughout the soil profile, infiltration and percolation rates are high. Surface runoff is then low, and additions to ground water can be high during periods of rainfall and snow melt, depending in part on how much water is needed to satisfy field capacity.

Of course, when the soil is capable of absorbing all the rain at maximum intensities, then increasing macropore space has no effect on infiltration. Also, when groundwater storage capacity is limited and easily satisfied, there is no gain to groundwater by improving the opportunity for more water to pass through the soil mantle.

Opportunity for retention storage determines the amount of water held permanently from streamflow. At any time, this storage opportunity depends on the amount of soil pore space between field capacity and the wilting percentage, and the proportion of this pore space that contains soil moisture. The first condition depends on depth, texture, and structure of the soil; the second condition depends on precipitation and on climatic and vegetative factors that affect evapo-transpiration. Thus, by altering the vegetative cover and thereby transpiration, retention storage opportunity may be changed and streamflow affected.

In New England, the storage capacity of humus has important storage implications because of the comparatively deep accumulations compared with warmer sections of the country. Average maximum humus depths are about 7 to 8 inches in northern New England, and about one-half as deep in southern New England (17).

Status of present knowledge.--What do we know about the effects of land treatment, particularly forest-land treatment, on soil moisture storage? For the White Mountain area no quantitative data on soil moisture storage are available. However, there are some well-known general relationships.

The soil under a fully stocked old-growth forest supposedly has the greatest detention storage of any cover type. It does not necessarily have the greatest retention storage, but in coarse-textured soils it may. Generally, upper soil horizons have greater detention storage than the lower, storage per unit depth decreasing with depth, at least to parent material. This is more pronounced under forests than under other types of cover. Detention storage is increased by organic matter, root penetration, and the activity of soil fauna and flora; it is decreased by com-

paction, fires, and repeated heavy cuttings.

Addition of organic matter to the soil increases the total storage capacity of the soil profile. In forested areas with potentially deep humus layers such as the White Mountains, significant changes in profile storage capacities may be made where soils are shallow and coarse-textured.

In certain soils, changes in detention or retention storage may be balanced partially by changes in the opposite direction: increasing detention storage by improving the structure of a tight clay may be partially compensated for in terms of total storage by some loss of retention storage.

Deficiencies in our knowledge.--No information exists on storage capacities of the soils in the White Mountain area. Nor are definitive data available on storage capacities of humus accumulations in different forest conditions.

Studies needed.--Two types of soil moisture storage information are needed. First, information on soil moisture storage values by horizons is needed for the major soil types and humus conditions. This may call for a survey-type sampling job. It would include determination of humus and mineral soil storage under representative forest types and soil types in undisturbed sapling, pole, and sawtimber stands. It would also involve a study of the influence of climatic, topographic, and soil variations on humus accumulation.

Then the effects of various forestry practices on humus accumulation and unit storage values by horizons and depths from surface should be determined for a number of soil-cover complexes. One suggestion is to study humus accumulation in experimental forests, taking advantage of the research history of treated stands. Old-growth forests that have been protected for long periods offer the best information source on normal humus depth in undisturbed conditions.

EVAPO-TRANSPIRATION

Research field.--By evapo-transpiration, water moves from the soil to the atmosphere in two ways. One is the physical process of evaporation from a water or land surface, but we are concerned mostly with evaporation from the soil. This process "involves the amount of energy received from the sun and the forces which hold water to the soil. The first varies principally with the time of day, season of year, and latitude; the second with the wetness and temperature of the soil, and the concentration of the soil solution" (6). To the factors listed above as bearing on the amount of energy received from the sun can be added aspect and slope percent of the area involved. The second process, transpiration, involves the plant from root hair to leaf. By this process the plant removes soil water and passes it off into the air.

Importance of the subject.--Most water that falls on the soil returns to the atmosphere by evapo-transpiration. Nationwide, 71 percent of our precipitation is evapo-transpired, leaving 29 percent for streamflow. In this area, no reliable data are available for small wooded watersheds, but, based on Langbein's report and local precipitation records, perhaps 40 percent returns to the atmosphere while 60 percent runs off (6). In relation to the importance of this process, Lull (8) says:

> As the soil dries, water supplies for plant growth are decreased while storage space for the next rainfall is increased. Therein reside the practical implications of evapo-transpiration for crop production, as a means of influencing the distribution of water supplies, and for flood control. Knowledge of evapo-transpiration rates is useful in scheduling delivery of irrigation water. The possibility of reducing transpiration by manipulation of vegetation, and thus increasing streamflow, has received recent attention. Conversely, the maintenance of heavy growths of vegetation which transpire maximum amounts of water and provide maximum amounts of storage space has application in flood control.

Status of present knowledge.--Though much is known of evapo-transpiration, little of the available information meets the needs of watershed-management research (1). Nearly all this information falls into one of four classes. One constitutes experimental determinations made in the laboratory or in soil-filled tanks (lysimeters). While informative, these data do not provide usable, quantitative answers. The second class of information comes from studies of entire watersheds. According to Colman: "Except for watersheds uniformly covered with one kind of vegetation, information of this kind does not provide sensitive measurements of evapo-transpiration for particular kinds or conditions of watershed cover." The third class constitutes calculations of evapo-transpiration potentials based essentially on records of precipitation and heat received at the ground. These "equation approaches" are for relatively large areas; and since they usually ignore the effects of vegetative cover they are inadequate to show treatment effects. The last class includes studies made on large plots employing measurements of soil moisture and precipitation. In these studies, evapo-transpiration rates have been calculated by studying moisture depletion from field capacity.

In the Northeast there have been no lysimeter or watershed studies designed to give evapo-transpiration data from forest cover; one study involving soil moisture measurements has been conducted (9).

Elsewhere research has shown the effect on evapo-transpiration of altering forest cover. Outstanding in the East is the work at the Coweeta Hydrologic Laboratory in the Southern Appalachians. At Coweeta, cutting a forest stand on a 33-acre watershed resulted in a 17-inch increase in streamflow the first year. Even though sprouts were cut annually, the effect on streamflow began diminishing after

the first year and leveled off after the third year, probably due to the increasing amounts of low vegetative cover such as grasses and weeds. Since then, the increased streamflow (compared to the pre-treatment period) has been 9 inches. In another study, where forest regrowth was allowed to take place after clear-cutting, water yield increase diminished in succeeding years as the trees grew back, but still twelve years after cutting, it was 4.9 inches above pretreatment yields.[6]

Recently work has been done that shows little, if any, evapo-transpiration differences among several types of forest cover. Reports by Moyle and Zahner (12) and by Zahner (19) show no appreciable differences in evapo-transpiration in the Southeast between pine and hardwood in undisturbed stands during the spring and summer growing season. Removal or deadening of a portion of the stand reduced evapo-transpiration. Soil-moisture measurements were made throughout the upper 48 inches of soil.

Lull and Axley (9) studied soil moisture depletion under pine and oak stands growing on deep sandy soils in New Jersey during the growing season of 1955. No difference was found between the soil moisture depletion rates under the two stands. Numerous studies are now under way in many parts of the United States to determine differences in evapo-transpiration between different types of forest, shrub, and herbaceous growth.

Some pertinent conclusions on evapo-transpiration, with particular pertinence to the field of forest waterhsed management research are summarized as follows:

- Evapo-transpiration, though it combines the processes of evaporation and transpiration, is studied as one process; there appears to be no need of trying to separate the two.
- The maximum amount of possible evapo-transpiration is the amount of soil moisture available for withdrawal. In areas with high water tables and along streams, this amount may exceed the amount of precipitation. In areas without high water tables the absolute, and rarely if ever attained, maximum is the amount of precipitation.
- The rate of evapo-transpiration depends on climate, soil-moisture supply, plant cover, and land management.
- Some investigators have minimized the effects of differences in types of plant cover, contending that with a given water supply and a complete plant cover the amount of evapo-transpiration depends almost solely on the amount of solar energy received by the surface and the resultant temperature. This ignores the factor of root depth, which varies with plants and affects the amount of soil moisture available for evapo-transpiration. This relationship is

[6] Unpublished report, U.S. Forest Service Southeastern Forest Experiment Station, 1955.

conditioned by depth of soil: on deep soils, natural differences in rooting depth of plants are clearly expressed in their effect on evapo-transpiration; with shallow soils, the roots of almost any plant cover utilize the soil moisture throughout the soil profile.

- Reduction in plant cover, such as forest thinning, is reflected in an increase in streamflow presumably because of a reduction in evapo-transpiration. This increase is reduced as vegetative recovery takes place. Among the more effective methods of increasing streamflow may be the elimination of riparian vegetation.

- Per unit of leaf area, hardwoods transpire more than conifers, but per tree of equal crown volume and per acre of well-stocked stands there may be little difference between them in the growing season. During cold winter weather neither type transpires appreciably. However, during periods of mild winter weather, transpiration of conifers may be much higher than that of bare deciduous trees.

- Evapo-transpiration in temperate and cold climates is less in winter than in summer. Evapo-transpiration decreases with increasing altitude and increasing latitude.

- As a rough estimate, evapo-transpiration from the spruce-fir type ranges between 10 and 20 inches and for northern hardwood 15 to 20 inches (4).

Deficiencies in knowledge.--For the White Mountain area no data are available on evapo-transpiration in relation to conditions on forest lands.

Type of studies needed.--In view of the lack of data and considering the complexities of evapo-transpiration, dependent as it is on a complex interplay of variables, both empirical and basic studies should be conducted: empirical, to obtain data on evapo-transpiration rates; and basic, to evaluate the factors involved so that experimental results may be applied to situations where the intensity of influential variables may differ from those of the study areas. Some emperical studies are:

- Determine the differences, by seasons, in evapo-transpiration from various cover types such as northern hardwoods, spruce-fir, white pine, grass or herbaceous growth, and denuded areas.

- Determine the effects on evapo-transpiration of various degrees and types of cutting, and the time lags involved in recovery of evapo-transpiration rates following stand disturbances. Determine if these effects can be related to basal area, canopy density, stand age, or other easily measured variables for purposes of prediction in the field.

The following studies may be basic, empirical, or a combination of both:

- Determine the effects of soil conditions. The following soil variables, because of their effects on soil mois-

ture and root habits, should be among these investigated: (a) soil drainage condition, including depth to water table, (b) soil texture, (c) soil depth, (d) stoniness, and (e) humus type and depth.

- Determine the effects of such topographic features as altitude, slope percent, and aspect.

- Determine the effects of metrological conditions: soil and air temperatures; wind conditions; amount of sunshine; and amount, timing, and nature of precipitation.

- In accordance with the "energy balance", determine possibility of accounting for the effects of topography and some of the climatic variables through solar radiation measurements.

Studies should be designed to make maximum use of sound interpolation procedures. It should not be necessary to study all variables in detail. A possible goal is the working out of good prediction methods using readily available and easily measured factors.

Considerable thought should be given methods to be used in measuring evapo-transpiration. For plot work such methods involve the measurement of soil moisture depletion from field capacity. A recent publication details various methods of measuring soil moisture (10).

The research methods (that is plot studies versus watershed studies) should be spelled out as clearly as possible before work is started so that the two types of research can be integrated. Investigation of evapo-transpiration lends itself to plot studies where rates can be measured and the relative influence of variables studied. Watershed studies should confirm the plot study findings in terms of runoff at the weir and facilitate application of the results to an area basis.

Plot studies of evapo-transpiration would necessarily be limited largely to the growing season and to upland sites. Soil moisture measurement cannot be used to determine evapo-transpiration when the soil is at or above field capacity most of the time. On areas where roots reach or approach the water table, evapo-transpiration research will probably entail groundwater-level studies.

STREAMFLOW

Research field.--Evaluation of the effects of physical and climatic features of a watershed on the behavior of streamflow.

Importance of subject.--Such land features of a watershed as size, shape, relief, elevation, aspect, and underlying rock structure have important hydrologic effects as do climatic conditions such as amount, form and distribution of precipitation, temperature pattern, humidity, amount of sunshine, and amount and direction of the wind.

The effect of forest management on streamflow is exerted within the basic framework of land and climatic characteristics. Though largely beyond the control of man, their effects must be defined: first, in order to separate them from the effects of land management; second, to facilitate the application of results from watershed management research; third, to obtain information for use in forecasting streamflow behavior, particularly flood routing.

Status of present knowledge.--We know something about the directional effects of these factors. For example: snow disappears from south slopes earlier than from north slopes; more snow accumulates at higher than at lower elevations; runoff from steep watersheds peaks quicker than from those with gentle topography; limestone bedrock often contains sinks and caves through which water flows freely underground from one watershed to another.

Deficiencies in knowledge.--Deficiencies in our knowledge of the effects of land features and climatic conditions on watershed relationships in this area are mostly quantitative. We cannot answer such questions as "How much?" or "When?"

Studies needed.--How far it is feasible or profitable to design research aimed at quantitative definition of land feature and climatic effects is problematical. It appears that our concern will be largely to separate these effects from land treatment effects.

Techniques of data analysis and streamflow prediction methods should be developed for our area. It should be profitable to study such streamflow characteristics as times of concentration and subsurface flow contributions. Differences between streamflow behavior on north and south slopes should be studied. Then too, a stream gage will be installed on Hubbard Brook proper and comparisons of runoff pattern will be made with the smaller sub-watersheds and also with larger streams gaged by the U. S. Geological Survey.

Research Program

THE research program of forest watershed management will require three types of studies: survey, plot, and gaged-watershed. Surveys will be conducted to gather information on some water problems, for instance, to determine the seriousness of water quality problems associated with landslides or logging roads. These should be informative, for they will entail not only examination of problems on-

the-ground but also exploratory research as to problem sources and solutions. These surveys will help develop the program of designed studies.

Plot studies will be conducted to determine the influence of hydrologic processes on disposition of precipitation under different forest conditions and treatments, to pre-test treatments before studying them on a gaged-watershed basis, to help explain integrated results at the weir, and to develop and test techniques for watershed research.

Plot studies, whenever they can be used in lieu of watershed studies, have three very distinct advantages over the latter: (1) they usually cost less than watershed studies and thus are more easily replicated; (2) suitable sites are more easily found since plots require less area and are not limited to accessible and gageable watersheds; (3) they offer greater possibilities for stratifying factors, and thus for making sounder investigations of single variable effects.

Watershed studies will involve those studies that utilize streamflow data and consequently deal with the end-product of watershed research. They also include those studies wherein the factors influencing streamflow--such as precipitation, snow accumulation and melt, or frost--are measured on a watershed basis.

Gaging watersheds is an expensive procedure. Because of the calibration period involved, it is also time-consuming. There are other difficulties. Watersheds that are physically suitable, reasonably accessible, and in ownerships where complete long-time control is possible, are relatively few. This makes it difficult to test a large number of variables except at great cost; it also greatly reduces the feasibility of replication. Another disadvantage: watersheds large enough to maintain continuous or nearly continuous streamflow usually differ in physical characteristics. Thus relationships between physical watershed variables and treatment sometimes obscure or distort treatment effects.

However, to date, gaging watersheds is the one known reliable method of accounting for effects of condition or treatment on runoff. This measured runoff, in conjunction with measured precipitation, gives the integrated answer to the net effects treatment has on streamflow. With a reliable, continuous record of runoff and precipitation it is possible to interpret treatment effects in terms of total flows, distribution of flow, and storm peaks. Storm and seasonal variables and timing effects can also be studied.

The number and kind of gaging studies needed will depend on the objectives and scope of the program, the opportunity for securing suitable gaging areas, and the degree to which plot studies are used to point out the need for and to supplement gaging studies.

As a general observation, stream-gaging should be used to measure the effects of extreme treatments and, at as few intermediate points as necessary, to establish the "shape of the curve". Stream-gaging results are the

"clinchers" as well as the sources of quantitative reference points from which relative plot study data may be interpolated.

WATER-QUALITY STUDIES

Water-quality studies involve analyzing roads and landslides as producers of sediment. In the main, the research program will be developed from surveys.

Road Studies

- Determine magnitude of the skid road problem by surveying logged areas. On these areas determination should be made of the amount of road disturbance, as a precent of area logged, and also in relation to the volume of cut. Truck and skid roads should be classified by percent grade. Possibilities of taking aerial photos to facilitate this study should be investigated.

  Intensity of disturbance and resulting erosion or erosion potential should be classified. This will involve arbitrary definitions of erosion classes such as "light", "medium", and "heavy". Potential erosion and rate of stabilization (perhaps as indicated by natural revegetation and recovery from compaction) should be noted. Ring infiltrometer tests might also be used to denote compaction conditions.

  Some considerations for choosing survey areas are: (a) type of logging (equipment and products), (b) season the area was logged, (c) length of time since logging, (d) physical features such as topography and soils, (e) timber types and conditions before and after logging.

- Based in part of the survey of existing road problems, a study should be set up at Hubbard Brook to determine the effects of grade and distance between drainage outlets on the nature, amount, and timing of erosion for representative local conditions. The opportunity for demonstration should be stressed in designing and installing this study.

- Determine the best methods of revegetating logging roads and decks in the area. A study of re-seeding methods now under way should be expanded. In addition, the effect on skid road erosion of scattering logging debris, spraying asphalt and cement, and the use of soil conditioners might be determined. These studies should disclose the length of time under all treatments, including no treatment, that it takes for road erosion to cease and the surface to revegetate or humus to form.

  Distinction should be made between skid roads to be abandoned to forest regrowth, and roads for later use. In the first case, re-seeding to improve soil conditions for tree growth should be considered--in addition to the water-

This study will involve the use of ring infiltrometers and also removal of soil cores and the application of laboratory techniques to measure percolation and pore space. Possibly runoff plots will be established. It should be possible to combine much of the plot work with research on evapo-transpiration.

- Plot studies should be designed to determine evapo-transpiration differences under several types of cover: northern hardwoods, spruce-fir, white pine, grass or other low cover, and bare areas. Plots should be located where soil, topographic, and climatic conditions are uniform for the cover types compared. The study will entail soil moisture measurements during a calibration period and after cover alteration. Several experimental areas may be required to compare cover effects fully. For example, plots might be set up in a hardwood area, where, following the calibration period, the types compared would be hardwoods, grass, bare. On another area spruce-fir and bare might be compared; at still another location white pine, grass, and bare might be studied.

Along with study of cover influences, it would be desirable to study effects of degrees and types of cutting and the time lags for recovery of evapo-transpiration rates following treatment. This work should correlate some measurable feature or combination of features such as basal area, canopy density, or stand age with evapo-transpiration.

On evapo-transpiration plots, it should also be possible to study many problems associated with snow interception and melt, surface runoff, percolation, soil moisture storage, humus conditions, and ground freezing.

- Plot studies should be made to determine the influence of cover, climatic, and topographic variables on snow accumulation and melt. Cover variables include:

a. Important forest cover types: northern hardwood, spruce-fir, and white pine. Eventually it may be desirable to study mixed hardwood-softwood stands, paper birch, hemlock, and red pine.

b. Densities. It will probably suffice to make this determination at only 2 to 4 points in the density scale--enough points for sound interpolation.

c. Age. This factor can be treated like density; i.e., a few points measured and considerable reliance placed on interpolation.

d. Stand structure. Some measure of the effect of even- versus uneven-aged stands should be made.

e. Shape and size of openings or cuttings should be studied to determine the most efficient opening for snow accumulation and retention.

Climatic variables that modify the effect of cover variables include snow depth at the beginning of melt peri-

patch versus strip, etc.), (2) intensity of cutting (degree of stand reduction below normal stocking by selective or clear-cutting certain parts), (3) frequency of cutting in terms of length of cutting cycle, and (4) type of forest management in relation to products (sawlog management versus pulpwood management). To some extent these groupings are related. One, or preferably two, similar treatments should be replicated on north and south aspects.

● Riparian cutting effects should be studied. Two types of areas might be studied: (1) a swampy section of Hubbard Brook in which maximum effect of roots in or near a water table can be measured; (2) an upland area where all vegetation along a stream course could be cut in a manner similar to the Coweeta study.

The three research projects outlined briefly here will require 12 to 18 gaged watersheds: six for cover-type studies, five to ten for cutting-practice studies, and one or two for riparian studies. Final decisions as to types of treatment and number of watersheds will be made after calibration and plot studies.

During the calibration period it is proposed to collect the following data:

a. Continuous record of runoff and precipitation.
b. Systematic measurement of water quality.
c. Snow and frost measurements in winter.
d. Climatic data.
e. Accurate boundary determination with good contour map.
f. Cover descriptions.
g. Detailed soils map.
h. Survey of humus conditions.

During the treatment period, measurements "a", "b", "c", "d", and "h" will be continued. Cover changes will be measured in detail.

Hydrologic Processes

● A study is needed to determine the effects of treatment on infiltration and percolation rates and on moisture storage constants. Plots should embrace at least two or three major cover and soil types and several treatments. Thorough analysis should be made of soil and cover factors before treatment and periodically after treatment to determine the reasons for change in parameters. Some plots might be established on experimental forests other than Hubbard Brook to take advantage of treatments already made.

Particular attention should be given to determining the relationship of humus type and depth to infiltration and soil-moisture storage and to factors that influence humus accumulation. Of equal importance is a study of the effect of frost on infiltration rates, also of the factors that influence frost formation such as snow depth and humus type and depth.

This study will involve the use of ring infiltrometers and also removal of soil cores and the application of laboratory techniques to measure percolation and pore space. Possibly runoff plots will be established. It should be possible to combine much of the plot work with research on evapo-transpiration.

- Plot studies should be designed to determine evapo-transpiration differences under several types of cover: northern hardwoods, spruce-fir, white pine, grass or other low cover, and bare areas. Plots should be located where soil, topographic, and climatic conditions are uniform for the cover types compared. The study will entail soil moisture measurements during a calibration period and after cover alteration. Several experimental areas may be required to compare cover effects fully. For example, plots might be set up in a hardwood area, where, following the calibration period, the types compared would be hardwoods, grass, bare. On another area spruce-fir and bare might be compared; at still another location white pine, grass, and bare might be studied.

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c. Age. This factor can be treated like density; i.e., a few points measured and considerable reliance placed on interpolation.

d. Stand structure. Some measure of the effect of even- versus uneven-aged stands should be made.

e. Shape and size of openings or cuttings should be studied to determine the most efficient opening for snow accumulation and retention.

Climatic variables that modify the effect of cover variables include snow depth at the beginning of melt peri-

od, and type of melt period determined by temperature, wind, and rainfall. Main topographic factors are elevation, aspect, and steepness of slope.

An attempt should be made to obtain an expression of stand canopy that will correlate well with snow interception and melt. Such a measurement could provide a useful tool for applying research findings on a practical basis. Paul E. Lemmon (7) describes a densiometer that might be used.

Also, topographic effects and some climatic effects on snow melt and evapo-transpiration should be tied to solar radiation measurements as a common denominator.

PRIORITIES

This analysis has brought out that the water problems of the White Mountains and of the areas downstream are largely problems of both high and low flows and water quality.

Since over 90 percent of the area is forested, we are working within a limited range of effects and treatments. Experience has shown that maximum differences in watershed behavior occur between undisturbed woods and cultivated fields. In the White Mountains, cultivated agricultural land is not a problem; so the range of maximum effects is reduced. Perhaps our legitimate range of treatment lies between undisturbed woods and grass land and where it might be feasible to convert woods to grass on municipal watersheds for the sake of water.

Within the forests of this region, the greatest differences in quantity and distribution of streamflow due to treatment seem to lie between extremes of stocking (both by age and density) and between extremes of cover types (northern hardwood and spruce-fir). Thus, of first importance is this question: What are the differences in runoff behavior between clear-cut areas and well-stocked woods in these two main cover types? Variations in stand conditions and cover types within these categories will produce differences within the range of maximum effects. The greater the maximum differences, the greater will be the effects of minor treatment variations and the more profitable it will be to study basic causes, effects, and methods of treatment.

Water quality problems resulting from forest land misuse appear to be less important in this region than in most. The field of research here is fairly well defined; i.e., road erosion, slides, and stream-cutting produce most of the sediment.

The question of roads, as they affect both water quantity and quality, is largely one of applied research. Since it is an important and immediate problem, it deserves considerable emphasis. We know that road practices can definitely affect water quality and surface runoff. And we know too that these practices are susceptible to management.

The subject of setting research priorities can be

approached in two ways: First, from the viewpoint of information desired, and second, as the assignment of project priorities. Theoretically, the two should be synonymous, but actually they are not. On the one hand, certain answers can be quickly obtained. On the other, because of the long-term nature of much forest research, particularly forest watershed research with its calibration periods and complex installations, some badly needed information will take a long time to get. Thus it will be many years before we can fully determine streamflow differences between a heavily forested and a denuded watershed--an important watershed problem. By contrast, determining the differences in relative infiltration rates between a mull and a mor can be done quickly.

Following is a list of proposed study priorities for the first 10-year period. It <u>is not</u> by priorities.

- Determine the magnitude of the logging road problem.
- Study the effect of road grade and distance, and location on erosion and stream pollution.
- Study methods of logging road stabilization.
- Survey the landslide problem.
- Begin studies on 6 to 10 gaged watersheds. This will entail the installation and maintenance of stream gages and climatic stations. It will involve measurements of snow and frost, water quality, and humus depth and type. It will also mean detailed soil surveys and cover descriptions of each gaged watershed as well as boundary marking and mapping.
- Determine the streamflow regimen of small forested watersheds in this region. Develop techniques of hydrologic analysis.
- Begin plot studies to define the relationship of climate and environment, (i.e., cover, soil, topography) to snow accumulation and melt, soil freezing, humus type and depth, infiltration, percolation, moisture storage, and evapo-transpiration.

By the end of this 10-year period, plot studies should have established the basic relationships between vegetative, physiographic, and climatic factors, and (1) snow accumulation and melt, and (2) soil freezing. Considerably more information should have been gathered on methods of logging road care to protect water values. From plot studies a body of data should be accumulating on the relationship between vegetative condition and evapo-transpiration.

During this period, studies not now envisioned will undoubtedly be initiated. Also, some studies now proposed will probably either be modified or dropped.

At the end of the first 10 years (1965), the program should be reviewed in the light of progress, the problem analysis, and changing conditions and perspectives. Follow-

ing the review, a new program should be outlined. At that time, consideration should be given to publishing a compilation of research findings during the first 10 years of the project and a prospectus of future work.

As now envisioned, a number of subwatersheds will be treated during the second 10-year period. All or most of the remaining gageable subwatersheds will then be gaged.

COORDINATION AND COOPERATION

Coordination

In all watershed studies, effort will be made to incorporate forest management research wherever there is the need and opportunity. Forest management research personnel will be familiar with the study objectives and the areas involved as a basis for considering integrated research. Not only in treatment of entire subwatersheds, but also in survey and plot studies, opportunities will arise for an integrated approach. This approach has already been initiated in special studies of logging roads. Another field of forest management involvement is in studies to determine the effects of cuttings on soil moisture conditions. Here it will be pertinent to study the effects of moisture differences on tree growth and reproduction. There will be other opportunities for dual research.

To apply the results of forest watershed management research it will be necessary to define forest conditions and types of treatment in standard forestry terms. To do this, watershed research will draw upon the measurement and evaluation techniques used in forest management.

Cooperation

The policy of the Forest Service in its research program is to cooperate with public agencies, forestry schools, private companies and individuals where it is in the interests of the public and of the research program to do so. This policy is being followed and will continue to be followed in the program of watershed management research. In this way it should be possible to utilize many fields of science or technology that bear upon the water problems. During the first year of operation, progress of the program was furthered by cooperative work with the Soil Conservation Service, the United States Geological Survey, and the Extension Service of the State of New Hampshire.

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